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FILING DATE.

APPLICATION NUMBER: 60/467,719

FILING DATE: May 02, 2003

RELATED PCT APPLICATION NUMBER: PCT/US03/21194

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Practitioner's Docket No. 100325.0194PRO2

PATENT



## IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: Satish Reddy, Jeffrey Scherffius and John Gilmartin

For: Improved Split Flow Process and Apparatus

### Box Provisional Patent Application

Commissioner for Patents

PO Box 1450

Alexandria, VA 22313-1450

### COVER SHEET FOR FILING PROVISIONAL APPLICATION (37 C.F.R. § 1.51(c)(1))

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 C.F.R. § 1.51(c)(1)(i). The following comprises the information required by 37 C.F.R. § 1.51(c)(1):

1. The following comprises the information required by 37 C.F.R. § 1.51(c)(1):

2. The names of the inventors are (37 C.F.R. § 1.51(c)(1)(ii)):

1. Satish Reddy
2. Jeffrey Scherffius
3. John Gilmartin

3. Residence addresses of the inventors, as numbered above (37 C.F.R. § 1.51(c)(1)(iii)):

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### EXPRESS MAILING UNDER 37 C.F.R. § 1.10\*

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I hereby certify that this paper, along with any document referred to, is being deposited with the United States Postal Service on this date May 2, 2003 in an envelope addressed to the Commissioner for Patents, Washington D.C. 20231 as "Express Mail Post Office to Addressee" Mailing Label No. EV193156875US.

Date: 5/2/03

4. The title of the invention is (37 C.F.R. § 1.51(c)(1)(iv)):

Improved Split Flow Process and Apparatus

5. The name, registration, customer and telephone numbers of the practitioner are (37 C.F.R. § 1.51(c)(1)(v)):

Name of practitioner: Martin Fessenmaier  
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Customer No. 34284

6. The docket number used to identify this application is (37 C.F.R. § 1.51(c)(1)(vi)):

Docket No. 100325.0194PRO2

7. The correspondence address for this application is (37 C.F.R. § 1.51(c)(1)(vii)):

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8. Statement as to whether invention was made by an agency of the U.S. Government or under contract with an agency of the U.S. Government. (37 C.F.R. § 1.51(c)(1)(viii)).

This invention was NOT made by an agency of the United States Government, or under contract with an agency of the United States Government.

9. Identification of documents accompanying this cover sheet:

A. Documents required by 37 C.F.R. § 1.51(c)(2)-(3):

Specification:	No. of pages	34
Drawings:	No. of sheets	0

B. Additional documents:

None

10. Fee

The filing fee for this provisional application, as set in 37 C.F.R. § 1.16(k), is \$160.00 for other than a small entity.

11. Fee payment

Fee payment in the amount of \$160.00 is being made at this time.

12. Method of fee payment

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# Fluor's Econamine FG Plus<sup>SM</sup> Technology

## An Enhanced Amine-Based CO<sub>2</sub> Capture Process

**FLUOR.**<sup>®</sup>

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Presented At:  
Second National Conference on Carbon Sequestration  
National Energy Technology Laboratory/Department of Energy  
Alexandria, VA  
May 5-8, 2003

*The Econamine FG<sup>SM</sup> and Econamine FG Plus<sup>SM</sup> technologies are Fluor proprietary amine-based carbon dioxide removal processes. All of the Econamine FG<sup>SM</sup> and Econamine FG Plus<sup>SM</sup> technology described in this paper is protected by existing or pending patents owned by Fluor.*



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**Background: Econamine FG<sup>SM</sup> Process**

The Econamine FG Plus<sup>SM</sup> technology is an advanced version of Fluor's Econamine FG<sup>SM</sup> technology, which has been used in 23 commercial plants for the recovery of carbon dioxide from flue gas.

Econamine FG<sup>SM</sup> technology uses monoethanolamine (MEA) as the basis of its solvent. However, the solvent formulation is specially designed to recover CO<sub>2</sub> from low pressure, oxygen-containing streams, such as burner flue gas streams. Therefore, it is a post-combustion CO<sub>2</sub> capture system and is easy to retrofit to existing facilities. Recovery of carbon dioxide from combined cycle gas turbine and coal-fired power plants is a good candidate for this technology. Chemical and fertilizer plants requiring additional CO<sub>2</sub> as a feedstock can also benefit from CO<sub>2</sub> recovery using this technology.

Carbon dioxide capture can be used for the following applications:

- CO<sub>2</sub> sequestration
- Enhanced oil recovery (EOR)
- Merchant CO<sub>2</sub> sales
- Chemical feedstock production

Most alkanolamine systems cannot operate in a flue gas environment, because the amine will rapidly degrade in the presence of oxygen.<sup>1</sup> This is prevented in the Econamine FG<sup>SM</sup> solvent by the addition of a proprietary inhibitor. This inhibitor also protects the equipment against corrosion and allows for conventional materials of construction, mostly carbon steel.

The Econamine FG<sup>SM</sup> flowsheet is similar to a generic gas treating process, which has been practiced for many years. All equipment items and operations are simple, reliable, and generally familiar to operating personnel. A typical Econamine FG<sup>SM</sup> flowsheet is presented in Figure 1, for reference.

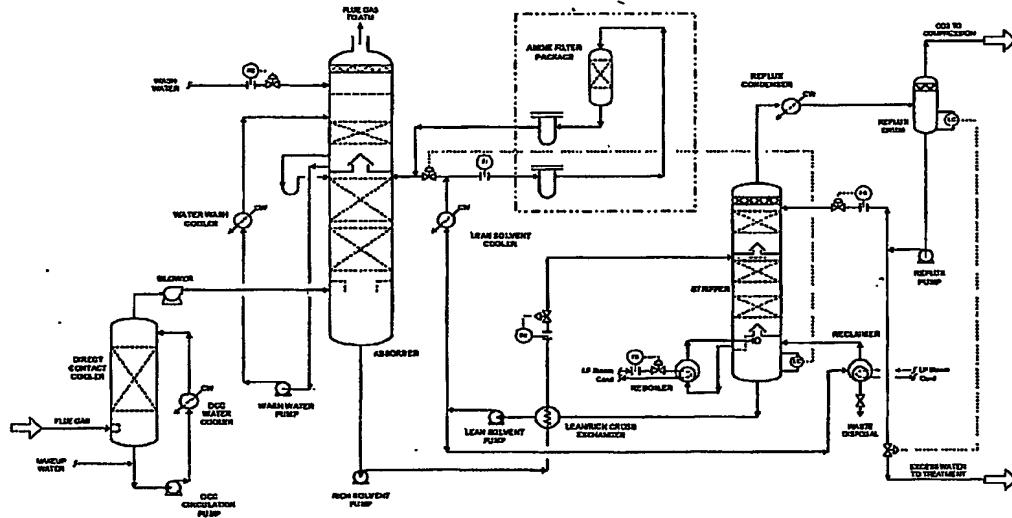


Figure 1: Typical Econamine FG<sup>SM</sup> Flowsheet

The Econamine FG<sup>SM</sup> process can be (and has been) safely located on a pressure sensitive CO<sub>2</sub> emitting source, such as a steam-methane reformer (SMR) flue gas line. At one facility in the USA, the Econamine



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FG<sup>SM</sup> plant is located on the exhaust duct of a gas turbine in a power plant, where neither a backpressure nor a pressure fluctuation can be tolerated. The technology is also located on reformer flue gas lines in India and Brazil. All of these plants consistently remove the carbon dioxide from the flue gas without disturbing the upstream pressure.

In order to avoid the formation of heat stable salts in the solution, SO<sub>x</sub>, NO<sub>x</sub> (specifically NO<sub>2</sub> and equivalent species), and particulates must be reduced to an acceptable level upstream of the Econamine FG<sup>SM</sup> absorber. This step can be incorporated into Fluor's total project solution for the Econamine FG<sup>SM</sup> or (Econamine FG Plus<sup>SM</sup>) CO<sub>2</sub> capture plant.

**Commercial Plant Example: FPL Facility at Bellingham, MA**

The Econamine FG<sup>SM</sup> technology has been successfully implemented at 23 commercial plants worldwide. One of these plants is a 360 STPD (327 Te/d) CO<sub>2</sub> recovery plant in the Florida Power and Light power plant in Bellingham, MA, USA. The Econamine FG<sup>SM</sup> plant was designed and constructed by Fluor, and has been in continuous operation since 1991.

This facility is the only commercial-scale CO<sub>2</sub> recovery unit in the world operating on gas turbine flue gas. This is notable for three reasons:

1. The CO<sub>2</sub> concentration in the flue gas is low, being only 2.8 to 3.1 vol%.
2. The oxygen concentration in the flue gas is high, being approximately 13 vol%.
3. Neither a backpressure nor a pressure fluctuation in the flue gas line can be tolerated.

The quality of the carbon dioxide product is suitable for use in the food and beverage industry. This is a better quality CO<sub>2</sub> than is needed for sequestration EOR.

Figure 2 shows an aerial view of the Bellingham Econamine FG<sup>SM</sup> plant. The plant design was based on air cooling only, hence the large bank of air coolers. The area shown in the picture also includes the CO<sub>2</sub> liquefaction, storage, and truck loading facilities. Figure 3 shows a ground level view of the absorber and stripper in the Bellingham facility.

Fluor has used the experience gained at the Bellingham facility to develop in-house expertise on amine degradation and corrosion prevention strategies. In fact, Fluor is the only technology vendor with long term commercial operating experience with CO<sub>2</sub> recovery from flue gas with a very high oxygen concentration. This translates into a more reliable and cost effective design and operation of the Econamine FG Plus<sup>SM</sup> plant.

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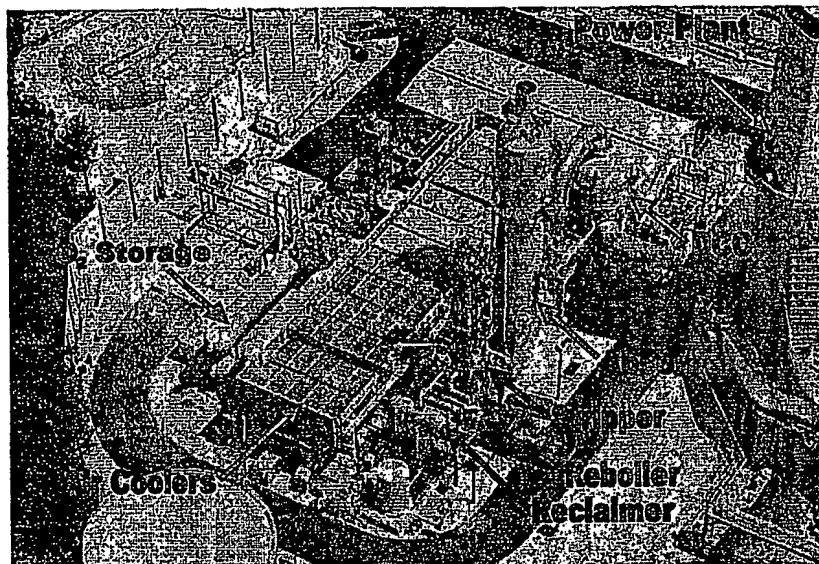


Figure 2: Bellingham Econamine FG<sup>SM</sup> Plant Aerial View

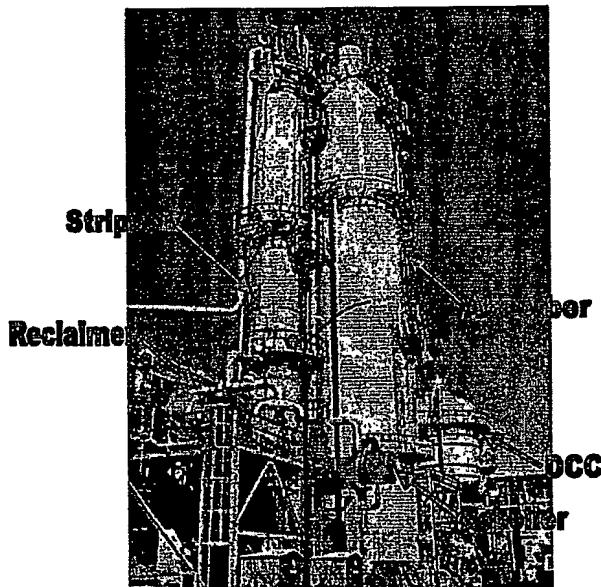


Figure 3: Bellingham Econamine FG<sup>SM</sup> Plant Ground View

#### Future of Carbon Dioxide Recovery Plants

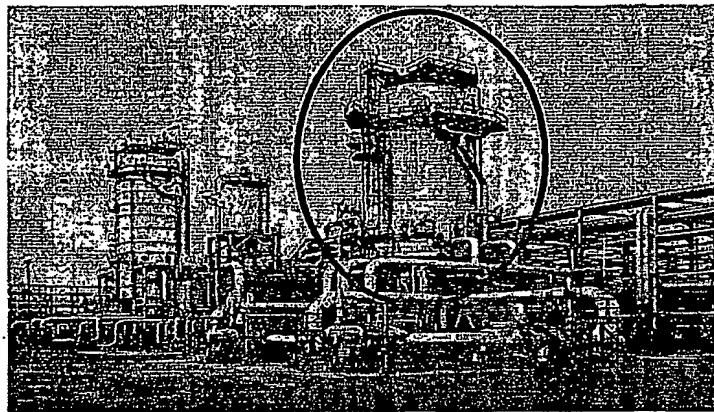
Large-scale carbon dioxide sequestration projects are currently being planned. With absorber diameters of 40 to 50 feet considered feasible (Figure 4), CO<sub>2</sub> recovery plant capacities of up to 8,000 Te/d are achievable, depending on the inlet flue gas CO<sub>2</sub> concentration. Even larger plants can be realized by



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employing multiple absorbers sharing a common stripper. The Econamine FG<sup>SM</sup> (and Econamine FG Plus<sup>SM</sup>) technology can be applied today to these large-scale CO<sub>2</sub> capture plants.



**Figure 4: The Saudi Aramco Econamine (DGA) Plant in Uthamaniyah, Saudi Arabia has an absorber (center-right) with a large diameter.**

**Econamine FG Plus<sup>SM</sup> Technology**

Using the Econamine FG<sup>SM</sup> technology and experience as a starting point, Fluor has developed an improved process called Econamine FG Plus<sup>SM</sup>. The new technology targets a goal of further lowering the energy consumption of the process. The Econamine FG Plus<sup>SM</sup> process is now being commercially offered.

The Econamine FG Plus<sup>SM</sup> technology consists of several pieces, including the following features:

- Improved solvent formulation
- Split flow configuration
- Stripping with condensate flash steam
- Absorber Intercooling
- Integrated steam generation

The above list serves as a menu of options from which a customized plant design can be developed to satisfy the specific requirements and operating parameters of each CO<sub>2</sub> removal application. In this way, Fluor can develop an optimized solution that minimizes the energy consumption, rather than offering only a standard design that was originally optimized for a different plant with different operating conditions.

**Improved Solvent Formulation**

An important feature of the Econamine FG Plus<sup>SM</sup> process is a new solvent formulation. The predominant amine for the solvent remains MEA, but the new formulation has the following benefits:

- Increased Reaction Rates: This decreases the required packing volume in the absorber, allowing a smaller, less expensive absorber.



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- Higher Solvent Capacity for CO<sub>2</sub>: Because the solvent is capable of carrying more CO<sub>2</sub>, less solvent circulation is required. This includes a decreased solvent flow through the stripper, thereby reducing the reboiler steam requirement.

Of course, the solvent still contains the proprietary inhibitor, and retains the low amine degradation and low corrosion qualities of the original Econamine FG<sup>SM</sup> solvent.

Split Flow Configuration

Another feature of the Econamine FG Plus<sup>SM</sup> process is a modified split flow configuration. In this configuration, two parallel regeneration schemes are utilized: flash regeneration and steam stripping.

The first portion of the rich solvent is regenerated in the stripper. Steam stripping removes the most carbon dioxide from the solvent and therefore provides the leanest solution, called lean solvent. A reboiler, requiring an external source of heat, provides the necessary energy to the stripper. This portion of solvent regeneration is identical to the standard Econamine FG<sup>SM</sup> stripper configuration.

The second portion of rich solvent is preheated against the lean solvent stream and then regenerated by flashing in a flash drum. The flashed solution contains more carbon dioxide than the lean solvent produced in the stripper, and is called semi-lean solvent. However, it is made without any additional steam requirement; the energy required for regeneration is provided by recovering the heat remaining in the lean solvent stream after it leaves the stripper reboiler.

Since some of the solvent entering the absorber has a higher loading with the split flow configuration, a higher circulation rate is required to meet the same recovery specification. However, the steam requirement is decreased because only a portion of the rich stream is being stripped to the leanest solution with external heat. As such, the split flow configuration decreases the energy consumption for the Econamine FG Plus<sup>SM</sup> process.

It should be noted that the increase in solvent circulation rate that results from the split flow configuration can be substantially mitigated by the implementation of the other Econamine FG Plus<sup>SM</sup> process features. As such, the overall solvent circulation rate of a complete Econamine FG Plus<sup>SM</sup> plant is only slightly higher than that of a standard Econamine FG<sup>SM</sup> plant.

Stripping with Condensate Flash Steam

This portion of the Econamine FG Plus<sup>SM</sup> technology is an extension of the split flow process. In order to decrease the partial pressure of the carbon dioxide above the semi-lean solvent in the flash drum, thereby decreasing the semi-lean solvent loading, steam is added to the flash drum. However, in order to avoid an increase in overall steam consumption, this steam is extracted from the saturated reboiler steam condensate by flashing the condensate at the semi-lean flash pressure. Hence, no additional steam is required.

The addition of steam to the semi-lean flash drum reduces the semi-lean loading, thereby decreasing the overall solvent circulation rate. The end effect is a decrease in the reboiler energy requirement.

Absorber Intercooling

Absorber intercooling is used to reduce the temperature in the middle of the absorber packed beds, as illustrated in Figure 5.



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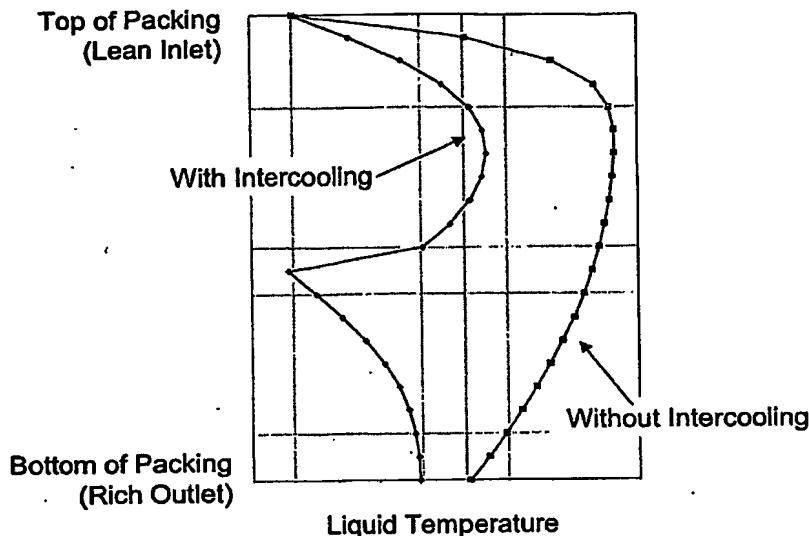


Figure 5: Absorber Temperature Profile with Intercooling

The intercooling has two major effects. First, the overall absorption rate of CO<sub>2</sub> is increased, decreasing the absorber size and capital cost.

Secondly, the rich solvent loading is increased, thereby decreasing the solvent circulation rate. The higher rich loading and the decreased solvent circulation rate both result in a decreased energy requirement in the stripper reboiler.

In a simple two-bed absorber, the cooling is accomplished by extracting the semi-rich solvent from the top (trim) bed of the absorber, cooling this solvent, and returning it to the bottom (bulk) bed of the absorber. If the absorber has more than two beds, then additional intercooling steps can be added.

If the process is a split flow configuration, the semi-rich solvent can be mixed with the semi-lean solvent prior to cooling. Alternatively, only the semi-lean solvent can be cooled without extracting the semi-rich solvent from the absorber. The intercooling philosophy depends on the Econamine FG Plus<sup>SM</sup> overall configuration and the specific operating parameters of the plant.

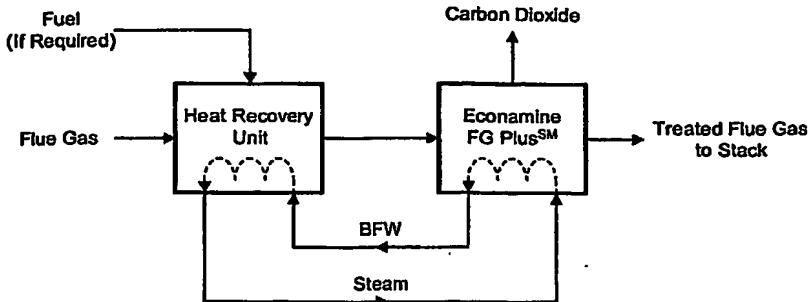
#### Integrated Steam Generation

Another way the Econamine FG Plus<sup>SM</sup> technology can save capital and operating costs is by integrating a steam generation system into the process (Figure 6). All of the Econamine FG Plus<sup>SM</sup> steam requirements can be met by such a system. This option is especially attractive when the Econamine FG Plus<sup>SM</sup> unit is added to the CO<sub>2</sub> producing plant as a retrofit and a new, dedicated steam generation unit is required.



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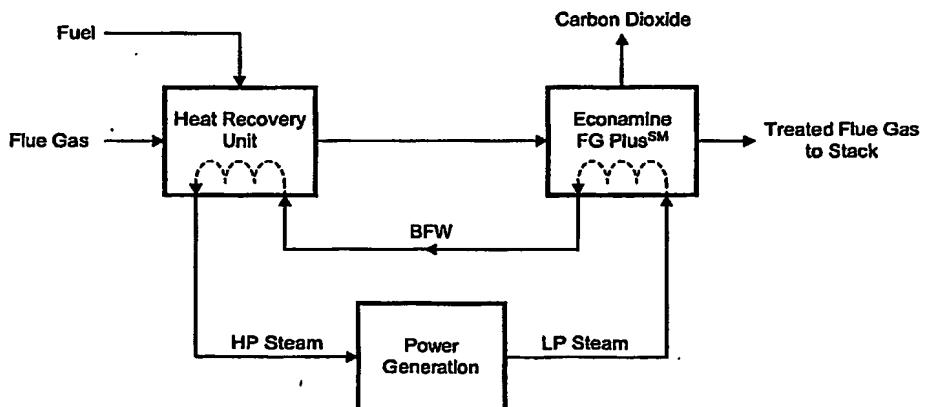


**Figure 6: Integrated Steam Generation Econamine FG Plus<sup>SM</sup> Plant**

There are two primary methods for generating the required steam:

1. If the flue gas temperature is high enough, the steam can be raised from heat recovery alone. Doing so not only generates steam, but it also decreases the load on the direct contact cooler. This scheme is potentially applicable to open cycle gas turbine power plants, furnaces, fired heaters, and any other process that produces a very high temperature flue gas.
2. In some cases, duct firing can be done in the flue gas upstream of the main Econamine FG Plus<sup>SM</sup> plant to generate heat, from which steam can be raised. This is done when the flue gas temperature is too low or the flue gas mass flow (i.e. heat flow) is too low to meet the steam requirement.

The duct-firing of the flue gas has the added advantage of increasing the CO<sub>2</sub> concentration in the absorber feed gas, thereby reducing the necessary removal rate of the Econamine FG Plus<sup>SM</sup> plant if a fixed quantity of CO<sub>2</sub> recovery is desired. If, instead, the CO<sub>2</sub> emission rate is fixed, then the recovery of the supplemental CO<sub>2</sub> is easier due to the higher gas concentration and the fact that a CO<sub>2</sub> recovery facility is already available on that stream. If the steam were raised in a separate boiler, boiler flue gas ducting and an additional blower would be required to route the flue gas to the Econamine FG Plus<sup>SM</sup> unit.



**Figure 7: Integrated Steam & Power Generation Econamine FG Plus<sup>SM</sup> Plant**



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Another option is to raise superheated high pressure steam that can first be used for power generation prior to being used as utility steam (Figure 7). This power could be used for the plant's pumps and blower or exported to other parts of the parent facility.

**Benefits of Econamine FG Plus<sup>SM</sup> Technology**

In addition to the added energy savings of the Econamine FG Plus<sup>SM</sup> technology, all of the benefits of the original Econamine FG<sup>SM</sup> remain. These benefits include:

- Fluor's Econamine FG Plus<sup>SM</sup> process is specially designed for removing carbon dioxide from low-pressure, oxygen-containing flue gas streams.
- The plant can be built with conventional materials of construction. The majority of the plant is constructed from carbon steel. Where the potential for corrosion is highest, stainless steel (usually 304SS) is used.
- The Econamine FG Plus<sup>SM</sup> technology does not require a custom-manufactured or expensive "boutique" solvent. The MEA solvent is readily available and inexpensive. In fact, it is the lowest cost amine available. MEA is produced by solvent manufacturers worldwide.
- The Econamine FG Plus<sup>SM</sup> process has the lowest heat requirement and the lowest solvent circulation rate (for a given configuration) versus all competing MEA-based processes.
- The Econamine FG<sup>SM</sup> technology has been successfully demonstrated in commercial applications with more than 20 plants licensed over the past 20 years. In this time, Fluor has further improved the process configuration to lower the energy consumption.

**Heat Integration with the Carbon Dioxide Producing Process**

Another method of achieving substantial energy savings is by comprehensive heat integration with the process that is producing the CO<sub>2</sub>. In this way, heat can be exchanged between process streams, thereby reducing the utility cooling water and steam demands.

Heat integration with power plants and refinery or petrochemical processing plants is feasible. In particular, heat integration with a power plant shows a good synergy. The Econamine FG Plus<sup>SM</sup> process-cooling can be accomplished by using vacuum condensate as the cooling source. In this way, the cooling water or air cooling load is minimized, and the heat is productively recovered by the vacuum condensate instead of wasted to a utility stream. Examples of suitable process coolers include the stripper overhead condenser, lean amine cooler, and semi-lean amine cooler.

**Comparison of Econamine FG Plus<sup>SM</sup> Technology with Other Amine Scrubbing Options**

The Econamine FG<sup>SM</sup> technology has been successfully demonstrated in over 20 commercial plants, including:

- The only CO<sub>2</sub> absorption plant anywhere in the world that recovers CO<sub>2</sub> at a commercial-scale from gas turbine flue gas
- A 1,000 Te/d (1,100 STPD) CO<sub>2</sub> recovery plant (for EOR)



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ABB Lummus Crest, using Kerr McGee Technology, has three commercial plants using and MEA based solvent.<sup>2</sup> However, its solvent strength is low compared to the Econamine FG Plus<sup>SM</sup> solvent strength. Because of this, the ABB Lummus Crest plants require both a higher circulation rate and higher reboiler duty than the base Econamine FG<sup>SM</sup> process and much more than the Econamine FG Plus<sup>SM</sup> process.

MHI/KEPCO have developed a process that uses a proprietary hindered amine known as KS-1. Only one commercial plant has been built.<sup>3</sup> The solvent cost is approximately 5 times the cost of MEA<sup>4,5</sup> (nearly 4.5 times the cost of Econamine FG Plus<sup>SM</sup> solvent). Although MHI claims that its solvent losses are much less than those of Econamine FG Plus<sup>SM</sup>, the annual cost of solvent replacement is approximately the same.

**Case Study: Comparison of Econamine FG Plus<sup>SM</sup> to KS-1**

MHI has published papers on the performance of its KS-1 solvent in the Petronas Fertilizer Co. CO<sub>2</sub> capture plant in Malaysia.<sup>3,6</sup> This is the only commercial installation of KS-1. Using this data, the performance of the Econamine FG Plus<sup>SM</sup> technology can be compared to KS-1.

The flue gas conditions are listed in Table 1. The gas source is flue gas from a steam reformer.

**Table 1: Petronas Fertilizer Co. Reformer Flue Gas Conditions**

Flow Rate	47,000 Nm <sup>3</sup> /h
Temperature	168 °C
Composition	
N <sub>2</sub>	67.79 % (v/v)
CO <sub>2</sub>	8.08 % (v/v)
O <sub>2</sub>	0.85 % (v/v)
Ar	1.00 % (v/v)
H <sub>2</sub> O	22.28 % (v/v)
SO <sub>x</sub>	2.44 ppm
NO <sub>x</sub>	200 ppm

The plant recovers 90% of the carbon dioxide for a total product rate of 160 Te/d. The product has a dry purity of over 99.9 vol% CO<sub>2</sub> and its pressure is 0.55 bar-g.

Table 2 shows the energy consumption and amine cost for the two processes.



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**Table 2: Comparison of Econamine FG Plus<sup>SM</sup> and KS-1**

	Units	Econamine FG Plus <sup>SM</sup>	KS-1
Energy Consumption	Btu/lb CO <sub>2</sub>	1395	1376
Solvent Replacement Cost	US\$/Te CO <sub>2</sub>	2.30	2.28

As seen in the table, the Econamine FG Plus<sup>SM</sup> technology requires virtually the same energy that MHI's KS-1 solvent. This is a significant improvement compared with the original Econamine FG Plus<sup>SM</sup> process energy requirement.

In addition, the solvent replacement costs are nearly identical. This is because although the KS-1 solvent loss is roughly 4.3 times less than that for Econamine FG Plus<sup>SM</sup>, the cost of KS-1 is 4.3 times more expensive than Econamine FG Plus<sup>SM</sup> solvent (MEA plus inhibitor).<sup>4,5</sup>

These results show that the Econamine FG Plus<sup>SM</sup> process is very competitive with KS-1. In addition, the experience of twenty years of operation and 23 commercial plants make Econamine FG Plus<sup>SM</sup> a very attractive solution for flue gas CO<sub>2</sub> recovery.

### Summary

The Econamine FG Plus<sup>SM</sup> process is an efficient, cost effective, and simple process for the removal of CO<sub>2</sub> from low-pressure, oxygen-containing flue gas streams. In developing the technology, Fluor has reduced the energy consumption below that of the original Econamine FG<sup>SM</sup> process, which was already the most efficient MEA-based process available. The Econamine FG Plus<sup>SM</sup> technology consists of several process features that can be assembled in many different combinations in order to provide a custom-fit solution to each carbon dioxide recovery application. When combined with heat integration with the parent CO<sub>2</sub> producing plant, additional substantial energy savings can be realized.

### References

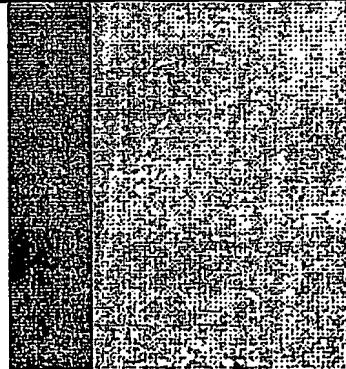
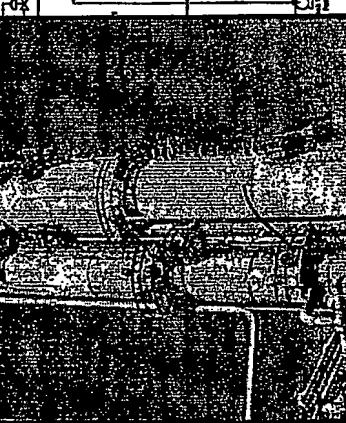
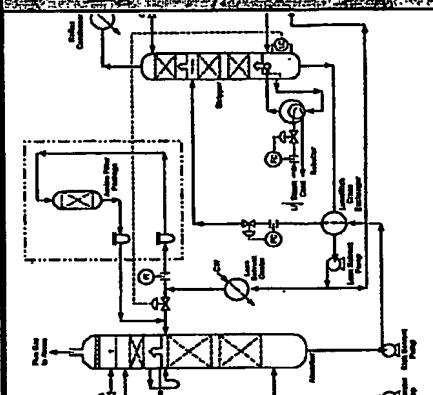
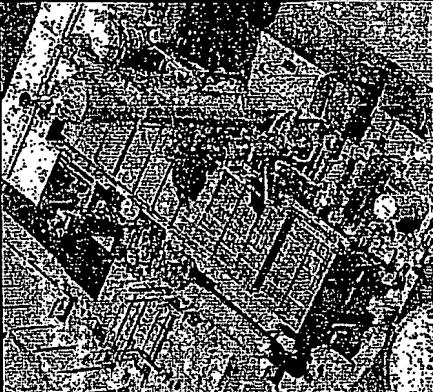
- <sup>1</sup> Kohl, A. L., and R. B. Nielsen, *Gas Purification*, 5<sup>th</sup> Ed., Gulf Publishing Company, 1997.
- <sup>2</sup> Barchas, R., and R. Davis, "The Kerr-McGee/Lummus Crest Technology for the Recovery of CO<sub>2</sub> from Stack Gases," First International Conference on Carbon Dioxide Removal, Amsterdam, The Netherlands, March 4-6, 1992.
- <sup>3</sup> Mimura, T., K. Matsumoto, M. Iijima, and S. Mitsuoka, "Development and Application of Flue Gas Carbon Dioxide Recovery Technology," Fifth International Conference on Greenhouse Gas Control Technologies, Cairns, Australia, August 13-16, 2000.
- <sup>4</sup> Mitsubishi Heavy Industries, Ltd., "Flue Gas CO<sub>2</sub> Capture (CO<sub>2</sub> Capture Technology of KS-1)," International Test Network for CO<sub>2</sub> Capture 4<sup>th</sup> Workshop, Kyoto, Japan, October, 2002.
- <sup>5</sup> *Chemical Market Reporter*, April 7, 2003.
- <sup>6</sup> Mitsubishi Heavy Industries, Ltd., "Flue Gas CO<sub>2</sub> Recovery Unit," *Japanese Advanced Environment Equipment*, Japan Society of Industrial Machinery Manufacturers, 2001.

# Fluor's Econamine FG Plus<sup>SM</sup> Technology

## An Enhanced Amine-Based CO<sub>2</sub> Capture Process

NETL Carbon  
Sequestration  
Conference  
May 2003

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## Presentation Outline

- ♦ Econamine FG<sup>SM</sup> Technology
- ♦ Econamine FG Plus<sup>SM</sup> Technology Features
- ♦ Heat Integration with the CO<sub>2</sub> Producing Process
- ♦ Comparison to other Amine Scrubbing Technologies

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## Patent Disclosure

- ♦ The following technologies, described in this presentation, are protected by existing or pending patents owned by Fluor
  - Econamine FG<sup>SM</sup>
  - Econamine FG Plus<sup>SM</sup> (all components)
  - Heat integration with a power plant or process facility
- ♦ Additional details of the process can be made available after a secrecy agreement has been signed

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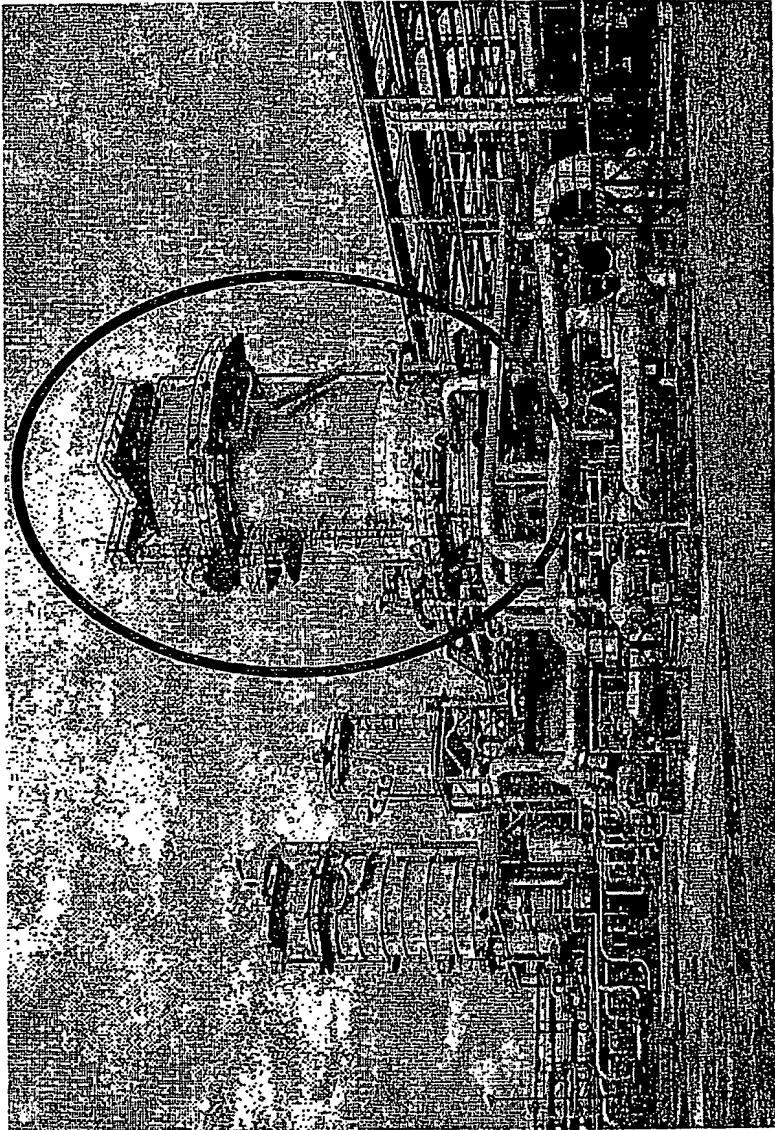
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## Econamine FGSM Process

- ♦ CO<sub>2</sub> capture via monoethanolamine (MEA) solution with proprietary inhibitor
- ♦ Technology permits the economical extraction of CO<sub>2</sub> from oxygen-containing streams, such as flue gas
- ♦ Post combustion CO<sub>2</sub> capture system
  - Applicable to existing facilities
  - CCGT and coal fired power plants are candidates
- ♦ SO<sub>X</sub>, NO<sub>X</sub>, and particulates must be removed upstream
  - Part of Fluor's total project solution
- ♦ Large scale CO<sub>2</sub> recovery plants are possible
  - 40 to 50 ft diameter absorbers are considered feasible
  - CO<sub>2</sub> recovery up to 8,000 Te/d per absorber

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## Example of Large Diameter Absorber



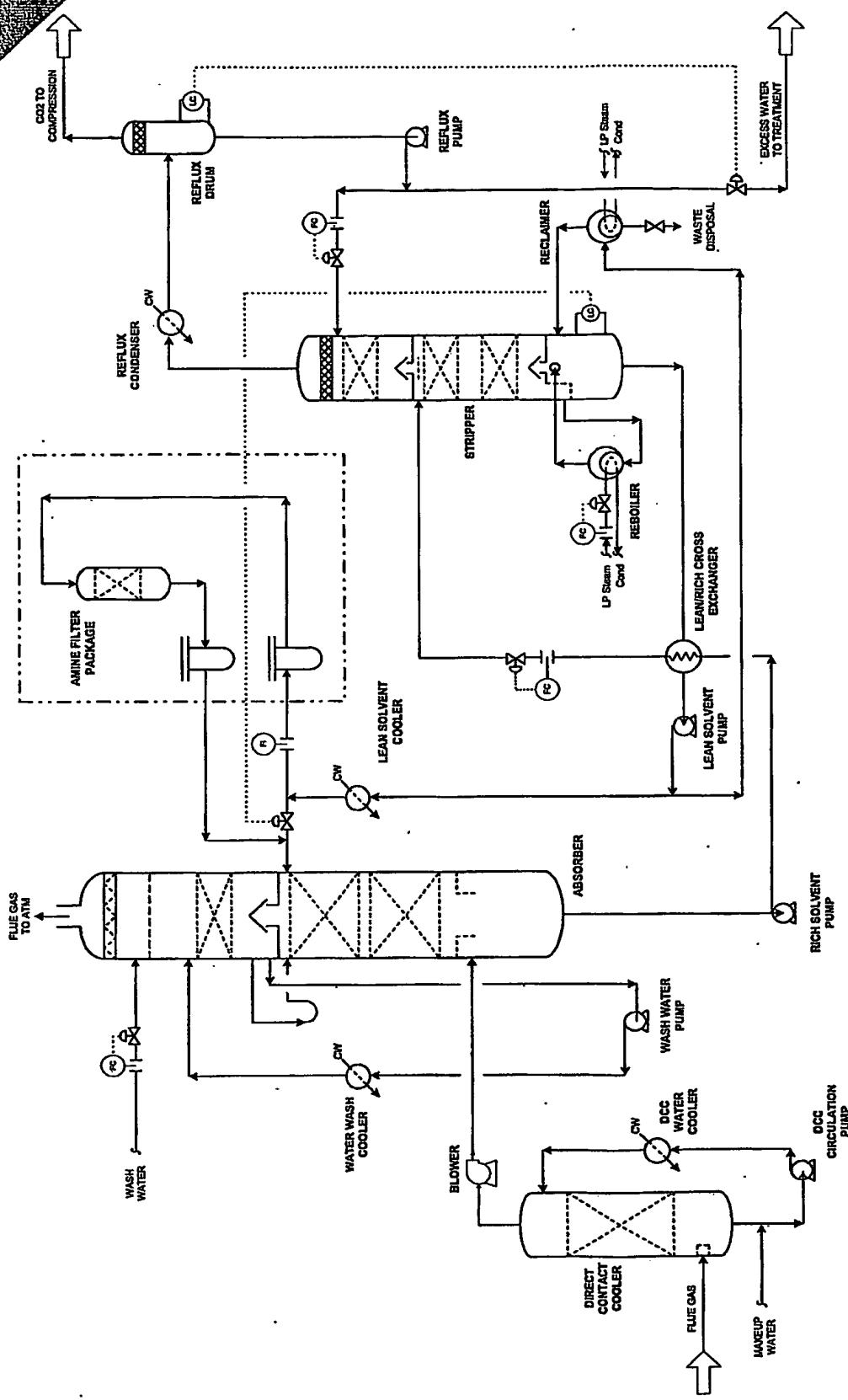
◆ Fluor-built Saudi Aramco Econamine (DGA) Plant  
– Uthamaniyah, Saudi Arabia

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## Econamine FGSM Features

- ♦ Econamine FGSM inhibitor protects the amine and the equipment
  - Allows CO<sub>2</sub> removal from oxygen-containing streams by preventing amine degradation
  - Allows conventional materials of construction, mostly carbon steel, by preventing corrosion
- ♦ Similar to generic gas treating processes employed for many years
  - Only simple, reliable equipment used in the process

Econamine FGSM Basic Flowsheet



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## Commercial Plant Example: FPL Facility at Bellingham, MA

- ◆ The only commercial-scale CO<sub>2</sub> recovery unit in the world operating on gas turbine flue gas
  - Only 2.8 - 3.1 vol% CO<sub>2</sub> in flue gas
  - Over 13 vol% O<sub>2</sub> in flue gas
- ◆ Recovery is 360 STPD (327 Te/d) of carbon dioxide
- ◆ Continuously operating since 1991
- ◆ Produces carbon dioxide product suitable for use in the food & beverage industry
  - Better quality than needed for CO<sub>2</sub> sequestration
- ◆ Designed and constructed by Fluor
  - Used by Fluor to develop know-how on amine degradation and corrosion prevention strategies

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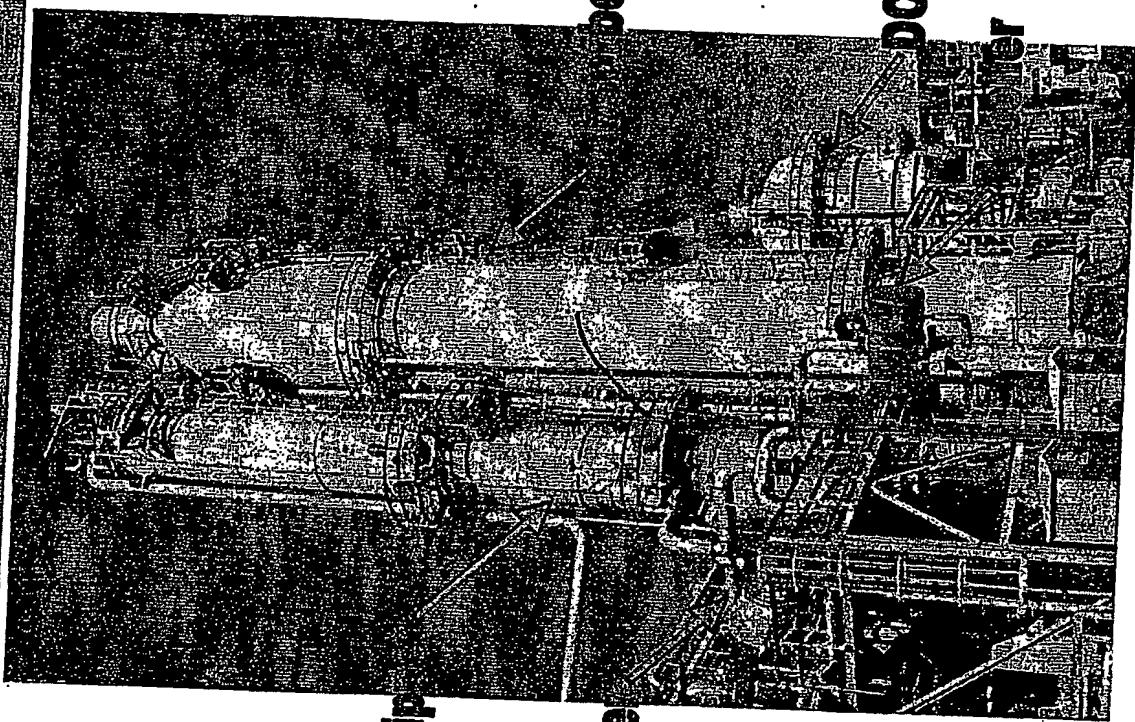
# Bellingham Plant Aerial View



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## Bellingham Plant Ground View



Reclaimer

Strip

Reclaimer

DCC

Reclaimer

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## Econamine FG Plus<sup>SM</sup> Features

- ◆ Fluor has developed an improved Econamine FGSM process, called Econamine FG Plus<sup>SM</sup>
- ◆ Process designed for lower energy consumption
- ◆ Econamine FG Plus<sup>SM</sup> process enhancements include:
  - Improved solvent formulation
  - Split flow configuration
  - Stripping with condensate flash steam
  - Absorber intercooling
  - Integrated steam generation
- ◆ Plant specifics dictate which features are included, thereby creating a customized and optimized facility

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## New Solvent Formulation

- ◆ Remains MEA-based
- ◆ Increased reaction rates
  - Decreased absorber size
- ◆ Higher solvent capacity for CO<sub>2</sub>
  - Lower circulation rate than standard Econamine FG<sup>SM</sup> solvent
  - Lower energy demand for regeneration

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## Split Flow Configuration

- ◆ Rich solvent split into two streams for parallel regeneration
  - One stream fed to stripper to generate lean solvent
    - Used for trim absorption in the top absorber bed
  - Second stream by-passes stripper and is preheated against process streams and flashed to generate semi-lean solvent
    - Used for bulk absorption in the bottom absorber bed
- ◆ Total circulation rate increases, but less energy is required
  - Increase in solvent rate is substantially mitigated with the implementation of the reformulated solvent

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## Stripping with Condensate Flash Steam

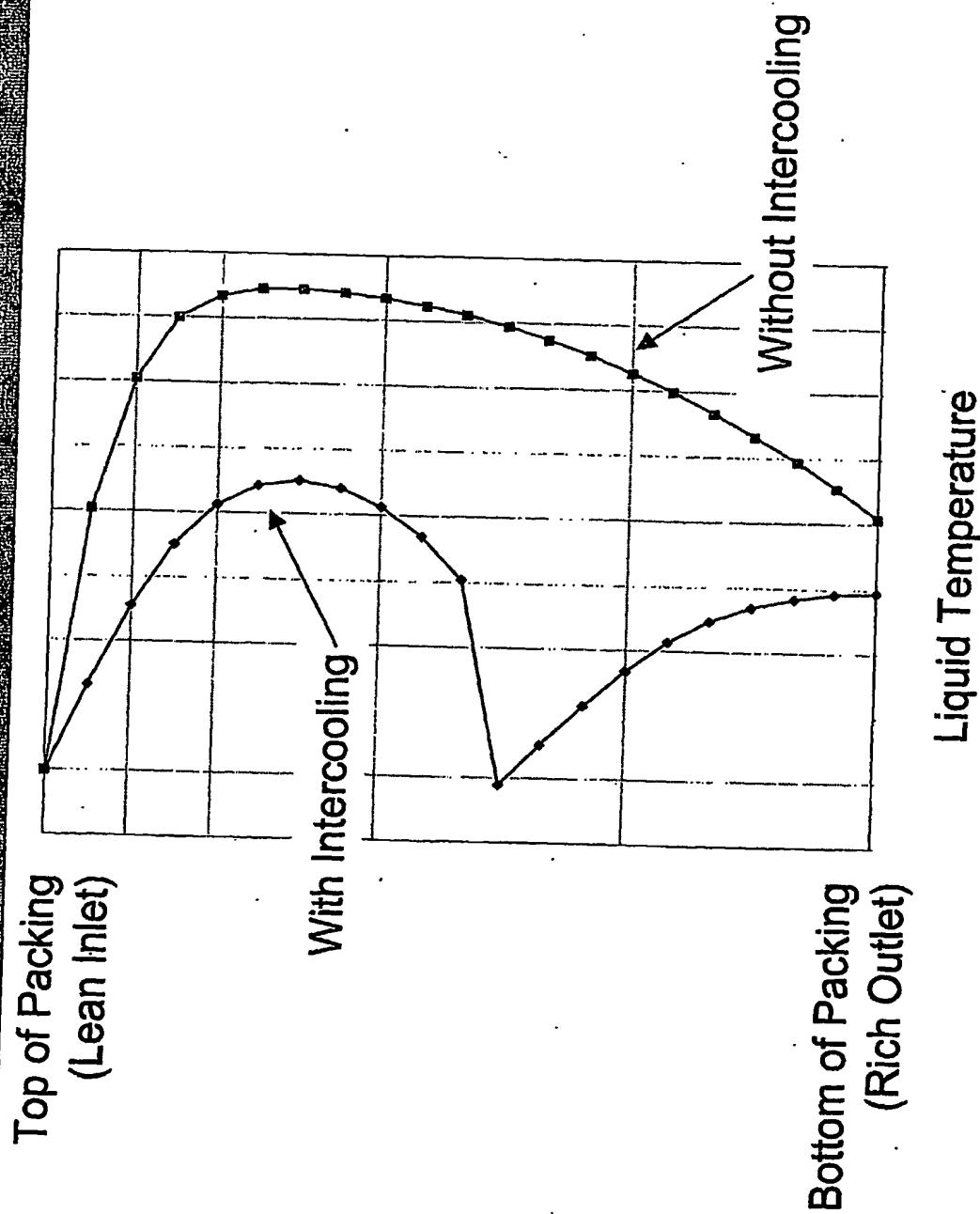
- ◆ Steam condensate (saturated) from the reboiler is let down to semi-lean flash drum pressure
- ◆ Condensate flash vapor (i.e. steam) is injected into the semi-lean flash drum as stripping medium, reducing semi-lean loading
- ◆ Requires lower circulation rate than split flow configuration alone
- ◆ Reboiler duty is further reduced

## Absorber Intercooling

- ◆ Semi-rich solvent flowing from the top (trim) bed is extracted from the column and is mixed with semi-lean solvent and cooled
- ◆ Cooled solvent is returned to the bottom (bulk) bed of the absorber
- ◆ Lower temperature increases the absorption rate
  - Decreased absorber size
- ◆ Increases rich solvent loading
  - Decreases circulation rate
  - Reduces energy requirement
- ◆ If the absorber has more than two beds, then additional intercooling steps can be added

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# Absorber Temperature Profile With Intercooling



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## Integrated Steam Generation

- ◆ Flue gas can be used to generate all steam requirements for the Econamine FG Plus<sup>SM</sup> plant
- ◆ If flue gas temperature is high, steam can be raised from heat recovery alone
- ◆ In addition, duct firing can be employed to raise additional steam
  - Added benefit of increasing CO<sub>2</sub> concentration to absorber
- ◆ Option: generate power by raising high-pressure steam

## Econamine FG Plus™ Benefits

- ♦ Low cost carbon steel materials of construction used for most equipment items
- ♦ MEA is the lowest cost amine and is readily available world-wide
- ♦ Annual inhibitor cost adds only approximately 20% to the MEA cost
- ♦ Lowest heat requirement for competing MEA-based processes
- ♦ Lowest solvent circulation rate for competing MEA-based processes

## Heat Integration with CO<sub>2</sub> Producing Process

- ◆ Heat integration with power/refinery/petrochemical process units is feasible
- ◆ Excellent integration opportunity with a power plant
  - Econamine FG Plus<sup>SM</sup> process cooling can be carried out with vacuum condensate
    - Stripper overhead condenser and absorber coolers provide heat to steam turbine vacuum condensate
  - Minimize steam and cooling water consumption
    - Substantial energy savings

## Amine Scrubbing Experience

- ◆ **Fluor Econamine FG<sup>SM</sup> & Econamine FG Plus<sup>SM</sup>**
  - Relatively high MEA concentration in solvent
    - Allows for reduced circulation rate and reboiler duty
  - 23 commercial plants, including:
    - Only commercial-scale CO<sub>2</sub> absorption plant on gas turbine flue gas
      - 1,000 Te/d CO<sub>2</sub> recovery plant for EOR
- ◆ **ABB Lummus; Kerr McGee Technology**
  - Lower MEA concentration than Econamine FG Plus<sup>SM</sup>
  - 3 commercial plants
- ◆ **MHI/KEPCO**
  - KS-1 hindered amine solvent
  - 1 commercial plant

Case Study: Comparison of Econamine FG  
Plus SM to MHI/KEPCO KS-1

- ♦ Basis is flue gas from Petronas Fertilizer Co. CO<sub>2</sub> capture plant in Malaysia
  - Only KS-1 commercial installation
  - MHI has published papers on its performance
- ♦ Flue gas source is steam reformer
  - 10.4 vol% (dry) CO<sub>2</sub>
  - 1.1 vol% (dry) O<sub>2</sub>
- ♦ CO<sub>2</sub> recovery is 160 Te/d
  - 90% recovery of incoming CO<sub>2</sub>

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Comparison of Econamine FG Plus<sup>SM</sup> to  
MHI/KEPCO KS-1

	Units	Econamine FG Plus <sup>SM</sup>	KS-1
Reboiler Steam Consumption	Btu/lb CO <sub>2</sub>	1395	1376
Solvent Replacement Cost	US\$/Te CO <sub>2</sub>	2.30	2.28

- ◆ Steam consumption is within 1.5% of each other
- ◆ Solvent replacement costs are nearly identical
  - KS-1 reported solvent loss is nearly 4.3 times less than Econamine FG Plus<sup>SM</sup>
  - BUT KS-1 purchase price is approximately 4.3 times more than Econamine FG Plus<sup>SM</sup>

## Summary

- ♦ The Econamine FG Plus<sup>SM</sup> process has reduced energy consumption
- ♦ If integrated with power/refinery/petrochemical process units, there can be further considerable saving in energy
- ♦ Econamine FG Plus<sup>SM</sup> technology allows CO<sub>2</sub> removal with low capital cost, low energy consumption and simple equipment

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